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EP 0623829 A1 US 5458147 A US 5225669 A
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(54) Abstract Title
Infrared detection system

(57) The energy consumed by an infrared detection system having at least one infrared transmitter and receiver pair (10, 15) to detect the presence of an object, eg to control a robotic vacuum cleaner, is kept to a minimum by processing circuitry (16). The processing circuitry changes the state of an electronic switching element such as a transistor (14) to charge a capacitor (11) with variable width charging pulses and then discharge the capacitor (11) through the infrared transmitter (10), resulting in the emission of a series of infrared signals of intensity determined by the respective charging pulse widths. The processing circuitry (16) also varies the width of subsequent charging pulses in dependence on whether the infrared receiver (15) detects a reflected signal above a predetermined threshold value, which is determined using integrator (18) and threshold detector (19).

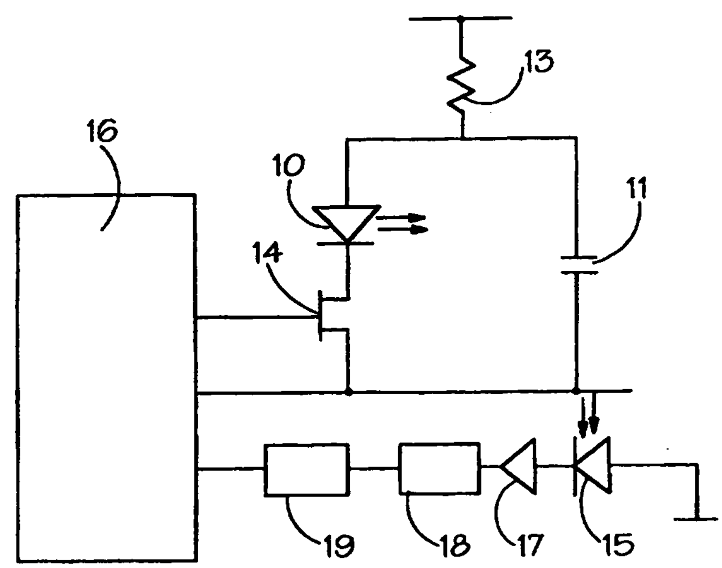

FIG.1.

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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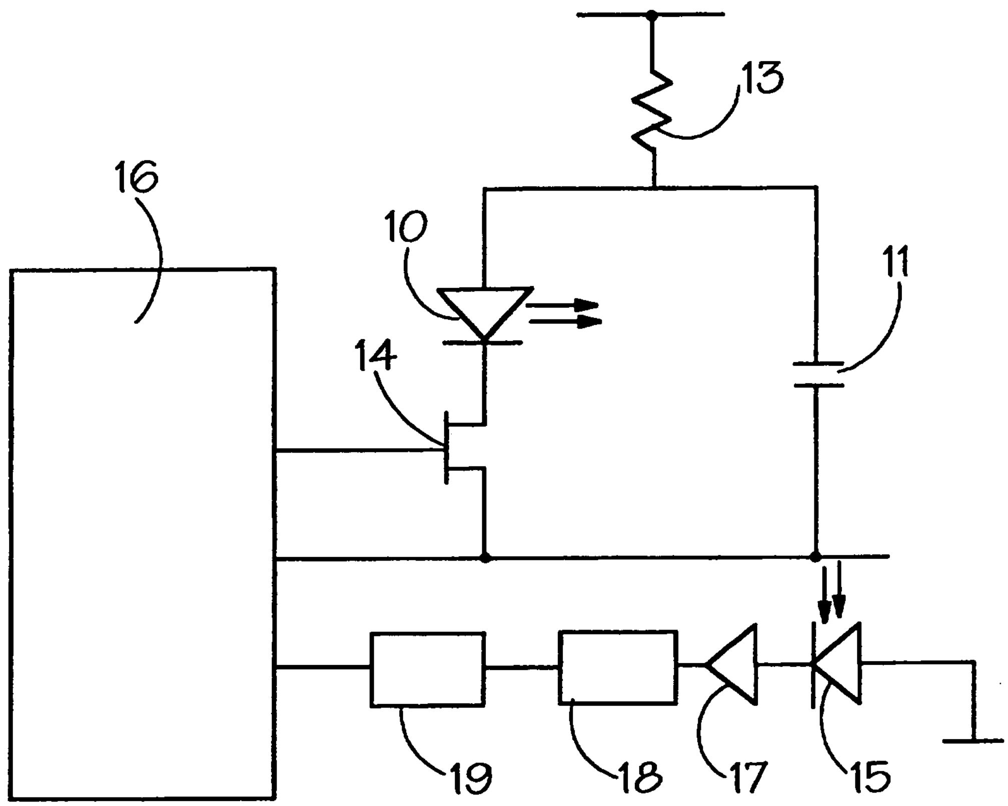


FIG.1.

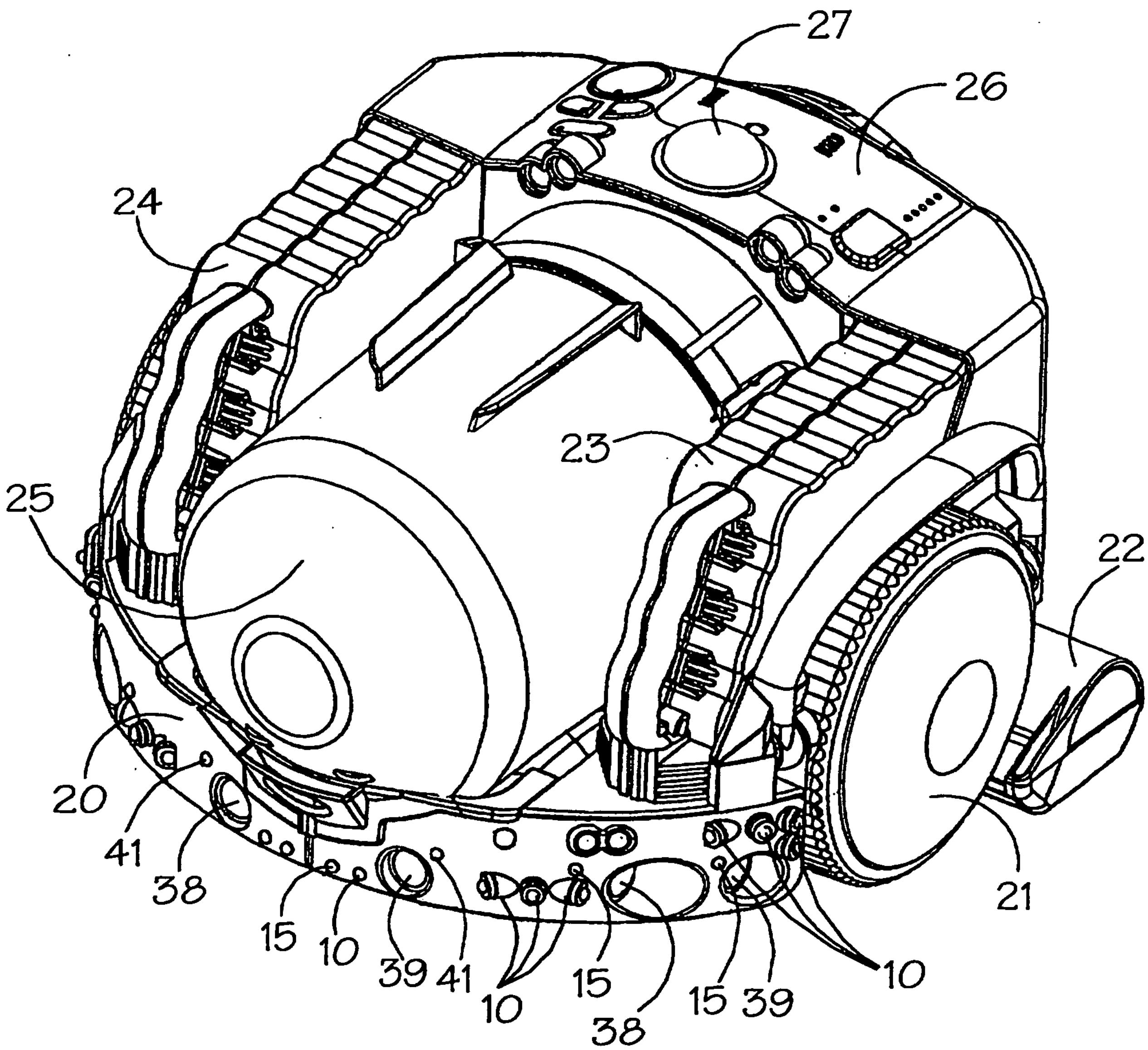
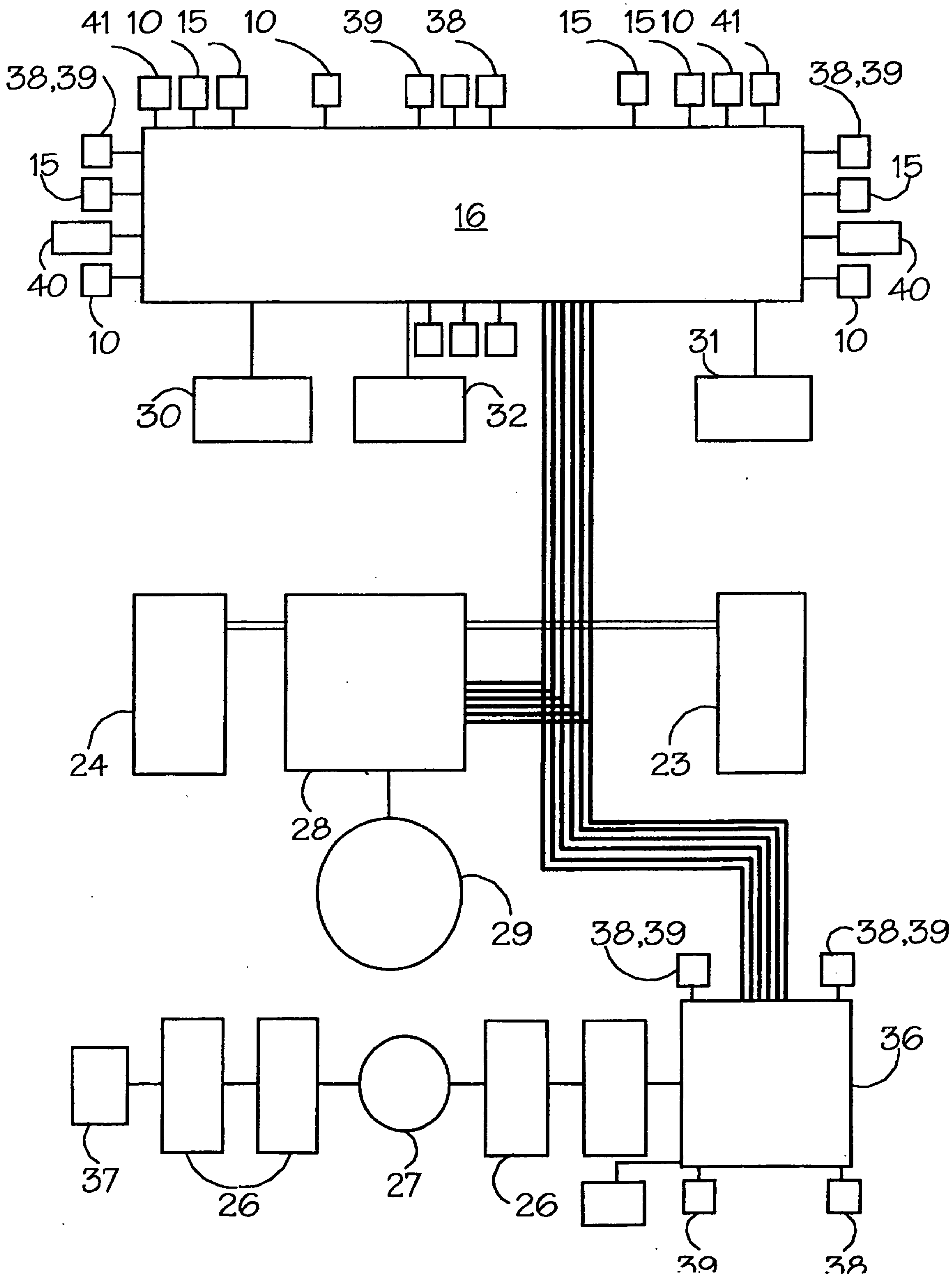


FIG.2.



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Detection System

This invention relates to an infra-red detection system and to an autonomous vehicle, such as a robotic cleaning device, equipped with such a detection system. The invention also relates to a method of detecting the presence of an object using an infra-red detection system.

It is known to use infra-red detection systems to detect distance from an object. Known systems comprise one or more infra-red transmitters and one or more infra-red receivers. Infra-red radiation is transmitted by the infra-red transmitters towards the object whose distance is to be measured, reflected thereby and received by the infra-red receivers. The system then calculates the perceived distance of the object depending on the amount of reflected radiation received. Conventionally, the infra-red transmitter transmits a continuous burst of identical pulses of infra-red radiation. This is energy consuming and it is often difficult to isolate the transmitted signal from a received signal. Some known systems provide a useful distance-measuring facility using high-current pulses. These can have a detrimental effect on the power supply to the device in which the system is utilised.

According to a first aspect of the present invention there is provided an infra-red detection system comprising at least one infra-red transmitter, at least one infra-red receiver, and means for causing the infra-red transmitter to emit a sequence of transmitted signals, wherein varying means are provided for varying the intensity of a subsequent signal in comparison to that of one or more previous signals in dependence upon the detection or otherwise by the infra-red receiver of a reflected signal above a predetermined threshold value.

Preferred and/or optional features of the first aspect of the invention are set out in claims 2 to 6 inclusive.

According to a second aspect of the invention there is provided a method of detecting the presence of an object using an infra-red detection system having at least one infra-red transmitter, at least one infra-red receiver, and means for causing the infra-red transmitter to emit a sequence of transmitted signals, wherein the intensity of a subsequent transmitted signal is varied in comparison to that of one or more previous transmitted signals in dependence upon the detection or otherwise by the infra-red receiver of a reflected signal above a predetermined threshold value.

Preferred and/or optional features of the second aspect of the invention are set out in claims 9 to18 inclusive.

By reducing the intensity of the transmitted signals wherever possible, excess energy consumption is avoided. It is thus possible to reduce the total energy consumed by the detection system in comparison to those systems known hitherto.

When a capacitor is included in the system to store energy which is subsequently discharged through the transmitter, the overall current drawn by the system is smoothed so that the demand from the power supply of the device in which the system is utilised is also smoothed.

A third aspect of the invention provides an autonomous vehicle equipped with an infra-red detection system according to the first aspect of the invention.

Preferred and/or optional features of the third aspect of the invention are set out in claims 21 to 25 inclusive.

The invention will now be more particularly described, by way of example only, with reference to the accompanying drawings, in which:-

Figure 1 is a circuit diagram showing one embodiment of an infra-red detection system according to the first aspect of the invention;

Figure 2 is a perspective view of a robotic vacuum cleaner incorporating an infra-red detection system as shown in Figure 1; and

Figure 3 is a circuit diagram of a power management system and a navigation system for the robotic vacuum cleaner shown in Figure 2.

Referring firstly to Figure 1 of the drawings, the infra-red detection system shown therein comprises an infra-red transmitter in the form of a light emitting diode 10, a storage capacitor 11, a charging resistor 13 and an electronic switching element in the form of a transistor 14 for discharging the capacitor 11 through the light emitting diode 10 when the transistor 14 is in a conductive state.

The infra-red detection system also comprises an infra-red receiver in the form of a photo-diode 15 for receiving infra-red radiation transmitted by the diode 10 and subsequently reflected from an object. The gate of the transistor 14 is connected to processing circuitry 16. The photo diode 15 is connected to an amplifier 17, which is connected to an integrator 18 and further to a threshold detector 19. The threshold detector 19 is connected to the processing circuitry 16.

When the transistor 14 is in a non-conductive state, the capacitor 11 is charged via the resistor 13. The capacitor 11 is then discharged through the light emitting diode 10 when the transistor 14 is switched to a conductive state by a discharge pulse produced by the processing circuitry 16. The amount to which the capacitor 11 is charged can be varied by varying the time for which the transistor 14 is held in a non-conductive state by way of a variable width pulse produced by the processing circuitry 16. This means that the intensity of the light pulse emitted through the light emitting diode 10 can be varied. The strength of any signal reflected by a given object and received by the photo diode 15 will thus depend partly on the distance of the object causing the reflection and partly on the intensity of the emitted light pulse.

Therefore, if an object is located at a specific distance from the appliance carrying the infra-red detection system, and if a reflected signal is received by the photo diode 15 when a signal of relatively high intensity is transmitted but not when a subsequent signal of lower intensity is transmitted, then, by suitable calibration of the signals transmitted, the appliance can determine the distance of the object, at least within certain limits.

The processing circuitry 16 generates a burst of charge pulses periodically. The first charge pulse in each burst has a width W_1. This holds the transistor 14 in a non-conductive state for time T_1 and the capacitor 11 charges to voltage V_1. The capacitor 11 is subsequently discharged through the diode 10 to produce a light of intensity I_1, which is dependent upon the voltage V_1. Any reflected signal received by the photo diode 15 is amplified by the amplifier 17, integrated by the integrater 18 and compared to a predetermined threshold value by the threshold detector 19. If a reflected signal above the predetermined threshold value is received, the processing circuitry 16 will reduce the width of the next charge pulse to width W_2 which is typically equal to half W_1, ie $W_1/2$. This second charge pulse will cause the time the transistor 14 is held in a non-conductive state to be reduced to time T_2, typically half T_1, ie $T_1/2$ and the capacitor 11 will, therefore, charge to a lower voltage V_2. When the capacitor 11 is subsequently discharged through the diode 10, the intensity I_2 of radiation emitted will be lower than I_1. If the photo diode 15 still receives a reflected signal above said predetermined threshold value, the processing circuitry 16 will again cause the width of the subsequent charge pulse W_3 to be reduced by a further half thereby further reducing the intensity I_3 of radiation emitted by the diode 10. This reduction in the width of the charge pulse will continue until the photo diode 15 fails to detect a reflected signal above said predetermined threshold value. When no reflected signal above the predetermined threshold value is detected by the photo diode 15, the processing circuitry 16 will emit a charge pulse of such a width that the intensity of the next transmitted signal is substantially halfway between the intensities of the last two transmitted signals. If, again, no reflected signal above the predetermined threshold value is received, a signal will be emitted which is again halfway between the

immediately preceding signal and the last signal to have resulted in a reflected signal being received at the photo diode 15. In this way, the intensity of the signal required to produce a reflected signal very close to the predetermined threshold value is determined. From this information, the distance of the detected object can be determined (within predetermined acceptable limits).

If, when the first signal of the sequence is transmitted, no reflected signal above the predetermined threshold value is received, the processing circuitry 16 will increase the width of the second charge pulse to a value which is substantially double that of W_1, i.e. $2W_1$. Assuming that a reflected signal is received, the process described above will be carried out from this starting point. If no reflected signal is received, and if the processing circuitry 16 has the capacity, the intensity of the transmitted signal can again be doubled. Alternatively, a fresh burst of transmitted signals can be commenced at the next appropriate time period.

In the above described embodiment, the maximum number of variations in the intensity of subsequent transmitted signals is 8. This provides sufficient accuracy for many applications. Furthermore, it is also envisaged that the maximum intensity of the transmitted signals can be varied according to the application to which the detection system is to be put.

If further refinement of the location of the object is required, the processing circuitry 16 generates a charging pulse of a width which is halfway between those of the pulse which produced the last reflected signal and the pulse which produced no reflected signal. If no reflected signal is produced, a subsequent pulse width would be halfway between those corresponding to the previous signal and the last reflected signal. Each time a signal produces no reflection, the subsequent signal is increased to an intensity which is essentially midway between the previous signal and the last reflected signal. If there is a reflection, the subsequent signal is decreased to an intensity which is essentially midway between the previous signal and the last unreflected signal. In this

way, the location of the object is refined to an acceptable level of accuracy suitable for use by the appliance in which the infra-red detector is located.

It is presently envisaged that the processing circuitry 16 will generate a charge pulse of half of the maximum width at the commencement of each burst of pulses. However, the first pulse of each burst of pulses could be of the same width as the last pulse of the previous burst. Alternatively, the first pulse of each burst could be half the width of the last pulse of the previous burst with the width of subsequent pulses being doubled (up to a maximum limit) until a reflected signal is received. In any event, the energy consumed by the infra-red detection system is less than a comparable system in which all of the pulses are of equal and maximum width and the receiving circuitry detects the amount of reflected signal.

One particular application of an infra-red detection system as described above is in an autonomous vehicle, typically a robotic cleaning device such as a robotic vacuum cleaner. The detection system can be used to detect, or assist in detecting, objects and in particular features of a room, such as walls and fireplaces, and items of furniture in the room.

An example of an autonomous vehicle in the form of a robotic vacuum cleaner is shown in Figure 2. The robotic vacuum cleaner comprises a main body 20, two drive wheels 21 (only one of which is shown), a brush bar housing 22, two rechargeable batteries 23 and 24, a cyclonic separator 25 of the type described in EP-A-0042723, a user interface 26, a light detector 27 (although there may be more than one such detector) and various sensors 10, 15, 38, 39, 40 and 41 which will be more particularly described hereinafter.

The light detector 27 comprises at least four, and typically eight, light detecting devices, e.g. photo transistors, equi-angularly spaced about a central axis and mounted in a plastics housing. The detecting devices are arranged in a horizontal plane for measuring light received at eight different compass points around the light detector 27. The signal from each light detecting device is fed into a filter network and then into an analogue-

to-digital converter before being passed to the processing circuitry 16. The light detector 27 is more particularly described in our co-pending British Patent Application No. 98 27771.8 and is used to help locate the autonomous vehicle in a room by identifying when the light detected by the light detector 27 is the same or substantially the same as light previously detected by the light detector 27.

As shown in the drawings, there are several infra-red transmitters 10 and several infra-red receivers 15. The receivers 15 are not coupled to specific transmitters 10 and may receive reflected infra-red radiation from more than one transmitter. The receivers 10 are multiplexed by the processing circuitry 16. They operate as described above to detect the presence of objects and obstacles in the room being cleaned and also to detect the presence of walls and other boundaries along which the cleaner is designed to move at a predetermined distance. Variations in the distance of the cleaner from a wall or other boundary can be detected and either corrected or compensated for if desired.

An example of an electrical circuit for operating the robotic vacuum cleaner is shown in Figure 3. The circuit comprises the two rechargeable batteries 23 and 24, a battery and motor management system 28, a motor 29 for driving a suction fan, motors 30 and 31 for driving the left and right hand wheels 21 of the vacuum cleaner, a motor 32 for driving a brush bar of the vacuum cleaner, the processing circuitry 16, a user interface board 36 and the light detector 27.

The robotic vacuum cleaner is also equipped with a plurality of ultrasonic transmitters 38 and ultrasonic receivers 39, threshold detectors 40 for detecting the presence of a portable threshold locator placed, for example, at the entrance to a room or at the edge of a staircase and one or more pyroelectric detectors 41 for detecting animals and fires. There are four main ultrasonic receivers 39 which face forwards, rearwards and to opposite sides of the robotic vacuum cleaner. The signals received by these receivers 39 not only provide information representative of distance from a feature of the room for from an item of furniture in the room but the amplitude and width of the received signals vary according to the type of material sensed.

In one mode of operation, the robotic vacuum cleaner is, typically, placed alongside a wall and energised to move forwardly along the edge of the room. The various sensors including the infra-red sensors 10, 15 will detect obstacles in the room and other room features, such as corners of a room and fireplaces, and the processing circuitry 16 will navigate the robotic cleaner in order to avoid any such obstacles and to change direction when a feature of the room is reached. At each significant change of direction, the processing circuitry 16 will store information received from the light detector 27 and also from the four main ultrasonic receivers 39. It will also store information on the direction in which the cleaner turns at each change of direction. It will constantly monitor the information received from the light detector 27 and the four main ultrasonic receivers 39 and compare this with information previously stored. When the robotic vacuum cleaner reaches a position in which the information received from the light detector 27 and the four main receivers 39 is the same or substantially the same as information previously stored, the processing circuitry 16 will determine that the robotic vacuum cleaner has completed a complete traverse around the room and is programmed to cause the robotic vacuum cleaner to step inwards (away from the wall) by one cleaner width or substantially one cleaner width. The processing circuitry 16 will then be able to identify further changes of direction by comparing the information received from the light detector 27 and the four main ultrasonic receivers 39 with previously stored information and this will enable the robotic vacuum cleaner to navigate itself around the room avoiding any obstacles in its path in a generally inwardly spiral manner. The manner of navigation is more clearly described in our pending British Application No. 98 27777.5.

If the robotic vacuum cleaner is initially placed in the middle of the room, it will travel until it finds a wall or obstacle. If it finds a wall it will then follow the path described above. If it finds a feature (such as a central fireplace) or an obstacle in the centre of the room, it will complete a circuit around that feature or obstacle and then follow a generally outwardly spiral path.

Claims:

1. An infra-red detection system comprising at least one infra-red transmitter, at least one infra-red receiver, and means for causing the infra-red transmitter to emit a sequence of transmitted signals, wherein varying means are provided for varying the intensity of a subsequent transmitted signal in comparison to that of one or more previous transmitted signals in dependence upon the detection or otherwise by the infra-red receiver of a reflected signal above a predetermined threshold value.

2. An infra-red detection system as claimed in claim 1, wherein the varying means comprise a capacitor, a charging component and a switching component for discharging the capacitor.

3. An infra-red detection system as claimed in claim 2, wherein the charging component comprises a resistor and the switching component comprises a transistor.

4. An infra-red detection system as claimed in any one of the preceding claims, wherein the infra-red receiver is connected to an integrator.

5. An infra-red detection system as claimed in claim 4, wherein the integrator is connected to a threshold detector.

6. An infra-red detection system as claimed in claim 4 or 5, wherein an amplifier is connected between the infra-red receiver and the integrator.

7. An infra-red detection system substantially as hereinbefore described with reference to Figure 1 of the accompanying drawings.

8. A method of detecting the presence of an object using an infra-red detection system having at least one infra-red transmitter, at least one infra-red receiver, and means for causing the infra-red transmitter to emit a sequence of transmitted signals,

wherein the intensity of a subsequent transmitted signal is varied in comparison to that of one or more previous transmitted signals in dependence upon the detection or otherwise by the infra-red receiver of a reflected signal above a predetermined threshold value.

9. A method as claimed in claim 8, wherein, if the infra-red receiver detects a reflected signal above the predetermined threshold value, the intensity of each subsequent transmitted signal is decreased until the infra-red receiver fails to detect a reflected signal above said predetermined threshold value.

10. A method as claimed in claim 9, wherein the intensity of each subsequent transmitted signal is decreased by or substantially by half.

11. A method as claimed in any one of claims 8 to 10, wherein, if the infra-red receiver fails to detect a reflected signal above the predetermined threshold value, the intensity of each subsequent transmitted signal is increased until the infra-red receiver detects a reflected signal above said predetermined threshold value.

12. A method as claimed in claim 11, wherein the intensity of each subsequent transmitted signal is increased by or substantially by a factor of two.

13. A method as claimed in any one of claims 8 to 12, wherein, if the infra-red receiver detects a reflected signal above the predetermined threshold value, the intensity of the subsequent transmitted signal is decreased to a value substantially midway between that of the preceding transmitted signal and that of the last transmitted signal in response to which no reflected signal above the threshold value was detected.

14. A method as claimed in any one of claims 8 to 13, wherein, if the infra-red receiver does not detect a reflected signal above the predetermined threshold value, the intensity of the subsequent transmitted signal is increased to a value substantially

midway between that of the preceding transmitted signal and that of the last transmitted signal in response to which a reflected signal above the threshold value was detected.

15. A method as claimed in any one of claims 8 to 14, wherein the sequence of transmitted signals comprises periodic bursts of transmitted signals.

16. A method as claimed in claim 15, wherein no more than eight variations in transmitted signal are permitted in any one burst of transmitted signals.

17. A method as claimed in claim 15 or 16, wherein the first transmitted signal of each burst is of a maximum intensity.

18. A method as claimed in claim 15 or 16, wherein the first transmitted signal of each burst is of an intensity which is substantially equal to half of a maximum intensity.

19. A method of detecting the presence of an object, using an infra-red detection system, substantially as hereinbefore described with reference to the accompanying drawings.

20. An autonomous vehicle equipped with an infra-red detection system as claimed in any one of claims 1 to 7.

21. An autonomous vehicle as claimed in claim 20, further comprising power operated means for moving the vehicle and means for causing the vehicle to change direction to avoid an obstacle detected by the infra-red detection system.

22. An autonomous vehicle as claimed in claim 20 or 21, wherein the infra-red detection system comprises a plurality of infra-red transmitters and a plurality of infra-red receivers and processing circuitry for multiplexing the receivers.

23. An autonomous vehicle as claimed in any one of claims 20 to 22, further comprising a navigation system for identifying the location of the vehicle.

24. An autonomous vehicle as claimed in any one of claims 20 to 23, in the form of a robotic cleaning device.

25. An autonomous vehicle as claimed in claim 24, in the form of a robotic vacuum cleaner.

26. An autonomous vehicle substantially as hereinbefore described with reference to the accompanying drawings.

Application No:	GB 9924899.9	**Examiner:**	Bob Clark
Claims searched:	1 and 8	**Date of search:**	14 January 2000

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): G1A (AAG, AFA, AFH, AMQM, AMQX)

Int Cl (Ed.7): G01S 7/483, 7/484, 17/02, 17/06, 17/10; G01V 8/10, 8/12; G08B 13/181, 13/183, 13/184

Other: Online: WPI, EPODOC, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	EP 0623829 A1	(ERWIN SICK) See abstract	1,8,9,11
X	US 5225669	(HASCH) Line 30 column 3 to line 24 column 4	1,8,9
X	US 5458147	(MAUERHOFER) Line 5 column 5 to line 47 column 4	1, 8-14
X	US 5142134	(KUNKEL) Line 58 column 3 to line 35 column 4	1,8,9,11
X	US 4851661	(EVERETT) Line 60 column 3 to line 61 column 4	1,8,11,12, 20,21

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